REDUCING PUMP POWER CONSUMPTION BY 40% (1000 KW) THROUGH IMPROVED PUMP MANAGEMENT IN A CENTRAL PLANT

S. Deng
Research Associate

M. Liu, Ph.D., P.E.
Associate Research Engineer
Energy Systems Laboratory
Texas A&M University System
College Station, TX

D. Turner, Ph.D., P.E.
Professor

ABSTRACT

Chilled water system data collection and field measurements performed at the Central Utility Plant of Texas A&M University revealed that 30 ~ 50 % of the primary pump head is consumed by manual and automatic valves being operated in a partially-opened condition.

A comprehensive analysis was performed to develop an improved pump management schedule. The results show potential savings of up to 40% of the pump power consumption without any capital investment. The optimized schedule is being implemented. This paper describes the method and presents results of the analysis and implementation.

INTRODUCTION

Energy management in chilled water systems of today's central utility plants can remarkably improve owners O&M (operation and maintenance) cost. Variable-speed pumping is highly recommended and widely applied in new system construction designs (Fair, 1996) and existing system renovations (Karalus, 1997). Primary-secondary pumping configuration is extensively adopted in the mean time (Utesch, 1995; Fair, 1996; Karalus, 1997). System operation savings have also been achieved from building side pumping management (Hattemer, 1996).

This paper presents our efforts to improve the chilled water system operation at the central plants of Texas A&M University. By optimizing primary loop operation schedules, pump power savings of over 40% are achieved.

FACILITY INFORMATION

As shown in Figure 1, the Texas A&M Main Campus has a total of 104 buildings with a total of 8,598,515 ft^2 conditioned floor area. All these buildings receive chilled water from the two central plants: the Central Utility Plant and the South Satellite Plant, which together have a total installed cooling capacity of 24,700 tons.

With a cooling capacity of 21,400 tons, The Central Utility Plant sends out chilled water through four loops: West, East, South, and Central. All these loops are interconnected through supply and return common headers in the Central Utility Plant and pipe connections over the campus. The South Satellite Plant is a complementary one with a capacity of 3,300 tons, connected to the South loop at about 2/3 of the way from the Central Utility Plant.

Central Utility Plant

Plant Description.

At the Central Utility Plant, the chilled water system does not have secondary pumps. Primary pumps are used to serve both the in-plant chilled water system (chillers and other components) and the loops at required pump head and flow rates.

As to the simplified Central Utility Plant chilled water system layout presented in Figure 2, there are four common headers: loop chilled water supply common header, loop chilled water return common header, double effect absorption chillers 1 ~ 4 inlet sub-common header and centrifugal chillers 9 ~ 12 inlet sub-common header (this common header can be enabled or disabled by manual valves on it). Four chilled water loops (East, South, Central and West) serving the main campus are connected to the loop supply common header and loop return common header.

Chillers 1 ~ 4 are 1500-ton, double effect absorption chillers. Five pumps support this cluster between the loop return common header and their inlet sub-common header. Figure 3 presents the pump curve. Each pump can provide 3,000 GPM to 7,500 GPM when the pump head varies from 197 feet to 117 feet. The coincident power consumption varies from 220 hp (164 kW) to 280 hp (209 kW).

Chillers 9 ~12 are 3350-ton centrifugal chillers, with four pumps between the loop return common header and their inlet sub-common header. Chillers 9, 10, and 11 are steam turbine driven while chiller 12 is electricity driven. Pumps 9, 10, and 11 are steam turbine driven. The pump curves are shown in

Figure 4. According to the manufacturer, at the design speed of 5,300 RPM, the chilled water flow varies from 5,000 GPM to 13,000 GPM, the pump head varies from 235 feet to 180 feet, and the coincident brake horse power varies from 455 hp (339 kW) to 675 hp (504 kW). The pump speed can be modulated by slowing down the turbine speed.

Figure 4 also presents a measured pump curve at the turbine speed of 4,800 RPM. Pump 12 is electricity driven, and when the water flow rate varies from 5000 GPM to 14,000 GPM, the pump head decreases from 235 feet to 150 feet. The coincident pump power consumption varies from 450 hp (336 kW) to 645 hp (481 kW).

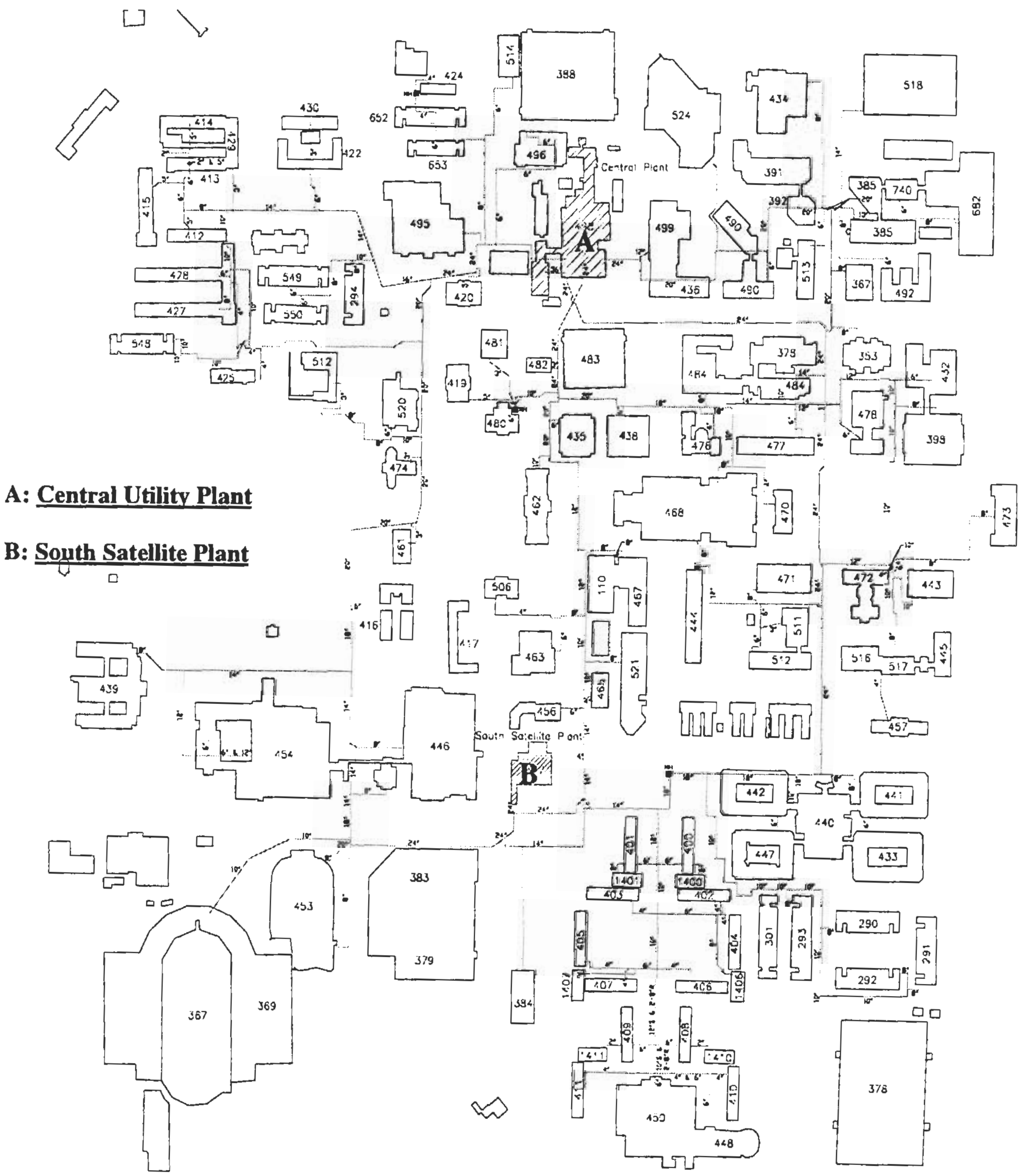

Figure 1. TAMU Main Campus Chilled Water Distribution Map

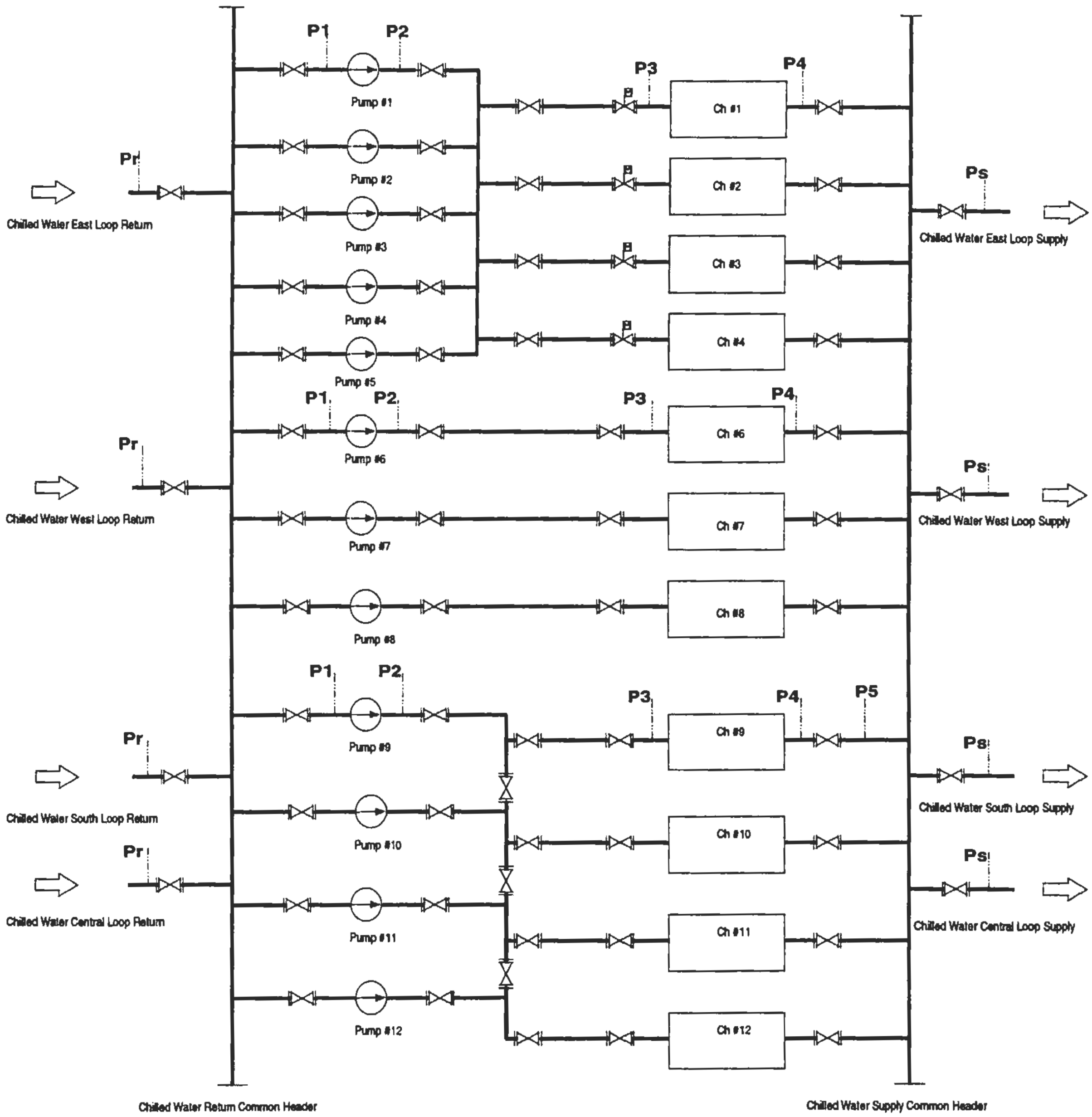

Figure 2. Simplified Chilled Water System Layout of the Central Utility Plant, TAMU

Operation Schedule.

The plant operation schedule which has been followed for years is presented in Table 1 under the column "Current Operation Schedule". For chillers 1 ~ 4, it has been found to be practical that 2 pumps support 3 chillers or 3 pumps supporting 4 chillers. For chillers 9 ~ 12, in fact, valves on their inlet sub-common header have been shut and chilled water loops for these chillers are isolated after primary pumps. In this way, dedicated primary pump operation has been applied.

Problems.

During the field visit, partially-opened manual valves were found in this chilled water system. Further field measurements revealed that these valves were consuming a large part of the pump head (up to 60 psi for one valve). Distribution of pressure losses is summarized in Table 2. Engineering calculation shows that 30 ~ 50 % of the pump head is consumed by partially-opened manual valves and automatic control valves, which means significant pumping energy waste is happening.

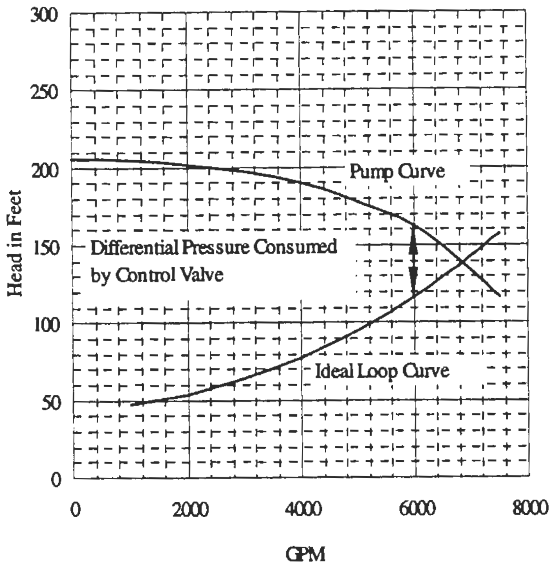

Figure 3. Pump Curve and Operation Analysis for Pumps # 1 ~ 5.

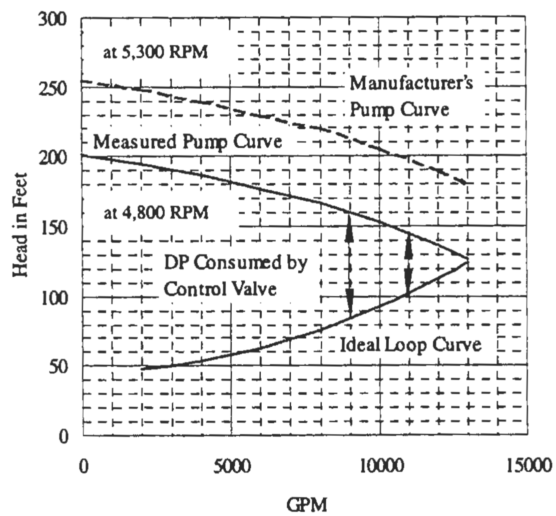

Figure 4. Pump Curve and Ideal Loop Curve for Pumps # 9 ~ 11

South Satellite Plant

Plant Description.

The South Satellite Plant chilled water system consists of three 1,100 tons centrifugal chillers and a primary-secondary pumping system. Design flow rate for each chiller is 2,600 GPM. As presented in Figure 5, three primary pumps support chillers by a inlet sub-common header. These pumps are constant speed pumps, with a rated flow rate of 3,300 GPM at a pump head of 26 psi. Motor size is 75 hp (56kW) each. Three secondary pumps with VFD control are connected to the chiller outlet sub-common header in parallel. Each of these pumps has a rated flow rate of 5,000 GPM at a pump head of 67 psi. Motor size is 250 hp (187 kW). A decoupler has been installed and used in this pumping system.

Table 1. Current and Recommended Central Plant Chilled Water Pump Operation Schedule

Chillers	Current Operation Schedule		Recommended Schedule	
	No. of Chillers	No. of Pumps	No. of Pumps	Savings (hp/kW)
1 ~ 4	1	1	1	0
	2	2	1	180/134
	3	2	2	0
	4	3	2	185/138
9 ~ 12	1	1	see text	see Table 4
	2	2		
	3	3		
	4	4		

Table 2. Distribution of Pressure Losses

Chiller	Main Loop	Chiller	Local[1] Resistance	Pump Head
unit	psi	psi	psi	psi
1	16	5	57	78
2	16	7	53	76
9	15	7	51	73
10	15	8	49	72
11	16	6	39	61

Operation Schedule.

Chillers have been interlocked with dedicated primary pumps. The number of secondary pumps in use and their VFD speeds are automatically controlled by computer program to achieve an adjustable secondary loop differential pressure setpoint. This setpoint is modulated from time to time by plant operators with the final goal to maintain a positive (from the campus return common header to campus supply common header, as marked in Figure 5) and relatively small (0 to 300 GPM) flow rate through the decoupler.

[1] Local Resistance includes resistance caused by pipe friction, fittings, elbows, and valves including, automatic valves, manual balance valves and check valves, etc., which are located in the Central Utilities Plant.

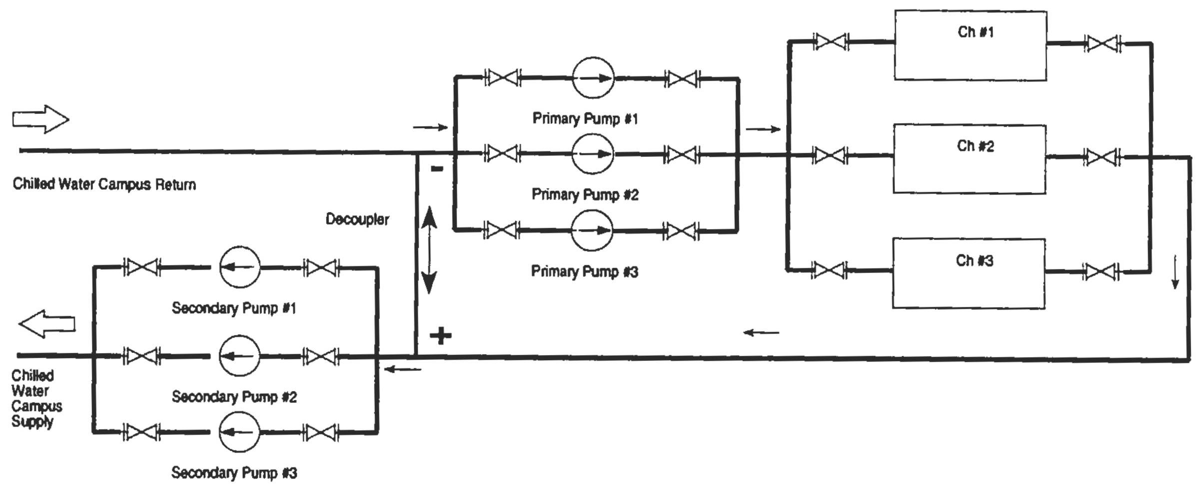

Figure 5. Simplified Chilled Water System Layout of the South Satellite Plant, TAMU

Problems.

During field measurements, the actual differential pressure for the primary loop was approximately 34 psi provided by primary pumps, which included 8 psi for the chillers and 13 psi for the pipe lines under the rated chiller flow rate. The other 13 psi was consumed by partially-opened manual valves. The secondary pumps were providing an actual head of less than 3 psi and were operated at very slow VFD speeds (about 20 %). Obviously, the pump head capacity (more than 100 psi) of the primary-secondary pumping system is more than enough compared with what is required by the in-plant chiller system and the campus loops (about 25 to 35 psi).

In the mean time, this traditional operation method which requires operators to indirectly control the decoupler flow by adjusting secondary loop DP setpoint whenever it is necessary is very inconvenient and challenging. It has not been strictly followed.

IMPROVED OPERATION SCHEDULE

Central Utility Plant

With engineering calculation and analysis, an optimized pump operation schedule is recommended to improve system efficiency. Details are shown in Table 1 under the column of "Recommended Schedule".

Chillers 1 ~ 4.

Figure 3 presents the results of pump operation analysis for pumps 1 ~ 5 when one pump provides chilled water to two chillers. The top curve represents the pump curve. The low curve represents the ideal loop curve (calculated from the conditions when all valves are fully open). The difference between the two curves will be consumed by the control valves. It appears that one pump can provide chilled water to two chillers.

Chillers 9 ~ 12.

The improved pump operation procedures are recommended as following:

(1) Fully open all the partially-opened manual valves in the chilled water lines, and open the isolation valves in the chiller inlet sub-common header.

(2) Operate chillers 9 ~ 11 with their dedicated pumps, and modulate the turbine speed(s) to provide adequate water flow through the chiller(s). When chiller 12 is turned on, do not turn on electrical pump 12, but modulate the turbine speed(s) of the in-use turbine pump(s) to provide enough water flow to the in-use turbine-driven chiller(s) and chiller 12.

South Satellite Plant

The improved pump operation schedule suggests that:

(1) Close the decoupler of the chilled water loop;

(2) Shut down the primary pumps;

(3) Interlock corresponding chiller and secondary pump, and provide required chilled water flow to chillers by programmed modulation of VFD speed under different loop conditions.

With help of software (control programs) modification, the above suggestions have been

Table 3. Chiller No. 9 Turbine Pump Test Results

Turbine Speed (RPM)	Chilled Water Flow (GPM)	Pump Head (psi)	Turbine Steam Flow (LB/Hr)	Manual Valve Position
4800	9700	72	6600	30 % open
4600	9900	62	6300	55% open
4300	9400	55	5500	55 % open
4000	8500	48	4700	55 % open
4000	9700	44	4700	100 % open

Table 4. Potential Savings of Improved Pump Operation Schedule for Chillers # 9 ~ 12

	Chiller 9	Chiller 10	Chillers 11 & 12		Total Savings	
Energy Unit	600 psi Steam (LB/Hr)	600 psi Steam (LB/Hr)	600 psi Steam (LB/Hr)	Electricity (kW)	600 psi Steam (LB/Hr)	Electricity (kW)
Potential Savings	3,200	3,200	-1,900	520	4,500	520

successfully carried out at the South Satellite Plant, and the plant is under good control.

MEASURED ENERGY SAVINGS

Remarkable amounts of pump power can be saved by opening partially-opened valves in the central plants and following the improved pump operation schedule.

Central Utility Plant

Chillers 1 ~ 4.

Because some modification work is in the process with absorption chillers # 1 ~ 4 of the Central Utility Plant, the recommended pump operation schedule has to be tested at a later time.

The potential savings are estimated based on the pump performance curve and typical flow rate conditions. The results are summarized in the last column of Table 1. Typically, around 180 hp (135 kW) will be saved under 2 or 4 chiller operation conditions.

Measured Results for Chillers 9 ~ 11.

During the plant operation, the improved pump operation procedures for chillers 9 ~ 12 are tested as following:

(1) Fully open all the partially-opened manual valves in the chilled water lines and slow down the turbine to provide adequate water flow through the chiller.

(2) Use one turbine pump to provide chilled water to two chillers (chiller 12 and one of the turbine-driven chillers).

Case (1) was tested on chillers 9 and 11 separately. The results for chiller No. 9 are summarized in Tables 3. Similar results were obtained on chiller No. 11.

The measured 600 psi steam reduction for pump 9 was 1,900 LB/Hr when the turbine speed was dropped from its original 4,800 RPM to 4,000 RPM. The estimated saving is 3,200 LB/Hr 600 psi steam if the turbine speed can be reduced to 3,600 RPM.

Case (2) was tested by using chillers 11 and 12. When pump 11 turbine speed was set at 5,300 rpm (the maximum speed under current control), testing showed that one steam turbine pump is capable of providing enough chilled water for two chillers. The use of the chiller inlet sub-common header in future operation will give even more safety factors for this kind of operation.

The 600 psi steam consumption of pump 11 was increased by 1,900 LB/Hr when it was operated at the maximum speed. But electricity pump 12 with a supporting motor size of 700 hp (522 kW) was never turned on during the test and was completely saved.

Savings from the improved pump operation procedures in testing cases (1) & (2) are summarized in Table 4.

South Satellite Plant

Besides that the operators are set "free" by the programmed control of the improved pump operation schedule at the South Satellite Plant, the plant itself works much smoother and efficiently.

With the traditional operation, the constant-speed primary pumps consumed 75 hp each, and most of the time two of the three 250-hp secondary pumps would be operated at the VFD speed of 20 ~ 40 %, which consumed about 2 ~ 16 hp (1.5 ~ 12 kW) each. Under current operation, chillers are operated with dedicated secondary pumps. VFD speed(s) were observed to be 45 %, 50 % and 60 % respectively, when one, two and three chiller(s) were in use during the test. So the pumping power savings are 50 hp (37 kW), 100 hp (75 kW) and 110 hp (82 kW) correspondingly.

Estimated Annual Savings

Since the annual savings depend on the number of chillers in operation and their combination, it is difficult to determine or project precisely these savings at the current time. However, the optimized annual chiller operation schedule will be developed as part of our on-going effort. By then, the annual saving will be determined actually.

CONCLUSIONS

The optimized pump operation schedules result in savings of up to 40 % in the TAMU central plants with capacity of 24,700 tons. Similar savings may be achieved in other similar plants without any capital investment.

ACKNOWLEDGMENTS

Work discussed in this paper was sponsored by the Central Utility Plant, Physical Plant Department, Texas A&M University under contract number 51190. We deeply appreciate all those involved for their contributions.

REFERENCES

Fair, J. 1996. "The Making of a Central Plant." Engineered Systems, Vol. 13, p. 118 - 121.

Hattemer, T. 1996. "Chilled Water Distribution System for an Urban University Campus." ASHRAE Journal, Vol. 38, p. 55 - 57.

Karalus, G. 1997. "Retrofitting a 30-Year-Old Water Distribution System." Heating, Piping, Air Conditioning, Vol. 69, p. 87 - 92.

Utesch, A. L. 1995. "Chilled Water Distribution." Heating, Piping, Air Conditioning, Vol. 67, p. 53 - 55.